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# MODELING THE EFFECT OF DRIFTS ON THE EDGE, SCRAPE-OFF LAYER, AND DIVERTOR PLASMA IN DIII-D[1]

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# 1 Introduction

Simulations of plasmas with a DIII-D shape indicate plasma drifts are important at power levels near the L- to H-mode plasma transition.[2] In addition to enhancing plasma flows in the divertor region, drifts are found to play a key role in establishing highly sheared radial electric fields in the edge of the confined plasma, for the physics of the high confinement operating mode (H-mode). Measurements of the plasma structure in the vicinity of the X-point of DIII-D indicate the importance of drifts on plasma flow between the scrape-off layer (SOL) and closed field lines.[3] The large electric fields provide large flows around the X-point, and these are conjectured to play a role in the transition from L- to H-mode confinement. These results indicate the relevance of modeling the edge and SOL plasmas of present tokamak devices using models which include E×B, ∇B, and pressure gradient drifts. The results of simulation of specific DIII-D discharges is reported in this paper. We start with discussion of the simulation of an Ohmic discharge in Section 2, including a study of the effect of varying several operational parameters. Simulation of a higher triangularity L-mode discharge is discussed in Section 3, and a summary is given in Section 4.

# 2 Simulation of Ohmic plasma

The initial simulation is for a low triangularity ($\delta$=0.33), 0.7 MW Ohmically heated lower single null DIII-D discharge. The outer strike point is positioned on the DIII-D bias ring, permitting biasing of the SOL. The plasma density at the top of the pedestal is $1\times10^{19}$ m$^{-3}$, with a radial scale length of about 2 cm at the outer midplane. The edge temperature profile is exponential, with a temperature of 100 eV at the top of the density pedestal and a radial scale length of 2 cm. This plasma is simulated with the UEDGE code, a

[1] This work was supported at LLNL by the U.S. DoE under contract W-7405-ENG-48 and at General Atomics under contract DE-AC03-99ER54463

[2] TD Rognlien, et.al., Phys. Plasma, 7(5), 1951-1958 (1999).

[3] MJ Schaffer, et.al., Phys. Plasma 8(5), 2118-2124 (2001).

2D fluid plasma code which simultaneously solves the particle continuity, electron and ion thermal transport, and the ion momentum equations, together with a fluid neutral model. Parallel transport is assumed classical, and perpendicular transport is assumed anomalous with spatially constant diffusion coefficients. The experimentally measured radial profiles of electron density and temperature at the outer midplane between the 96% and 110% poloidal flux surfaces are well fit with particle and thermal diffusivities of $D_\perp$=0.35 $m^2/s$, and $\chi_e=\chi_i$=1.8 $m^2/s$.

Inclusion of plasma drifts produce poloidal asymmetries on the closed field lines, as shown in Fig. 1. The plasma potential has a local maximum just above the X-point, and a minimum at the top of the device. This structure is created primarily by the ion ∇B drift, which is toward the X-point for this discharge. The ∇B drift creates a density minimum at the top of the plasma, and a maximum above the X-point. The local density extrema create local pressure and potential extrema ($\Delta p/p \sim \pm 25\%$) on the closed lines. The parallel pressure gradients are supported by parallel viscosity which is used in the parallel momentum equation to account for coupling between perpendicular and parallel pressure in a spatially varying magnetic field. In addition to the overall structure of the plasma potential determined by the ∇B drift, there is local structure obtained from the effect of the E×B drift.

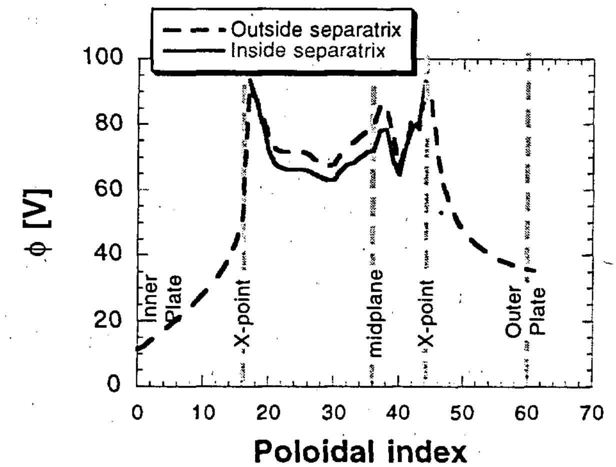

*Figure 1 Variation of the plasma potential on a flux surface just inside and just outside the separatrix.*

Plasma drifts create large radial flows. The vertical ∇B drift has a radial component except at the midplane. The resulting radial velocity exceeds that obtained from anomalous diffusion, creating a flow into the closed lines at the top of the plasma, and into the SOL at the bottom. Additional radial flows, which are competitive with diffuison, are created by the poloidal electric field, particularly around the potential maximum above the X-point.

## 2.1 Effect of toroidal field direction

The poloidal variation of the plasma parameters changes significantly when the ion ∇B drift direction is reversed by reversing the toroidal magnetic field, as shown in Fig. 2. The potential minimum at the top of the plasma becomes a maximum, and the maximum above the X-point is eliminated. The electric field shear is dramatically reduced by reversing the toroidal field, as shown in Fig. 2(b). It is believed that a transition to H-mode is obtained

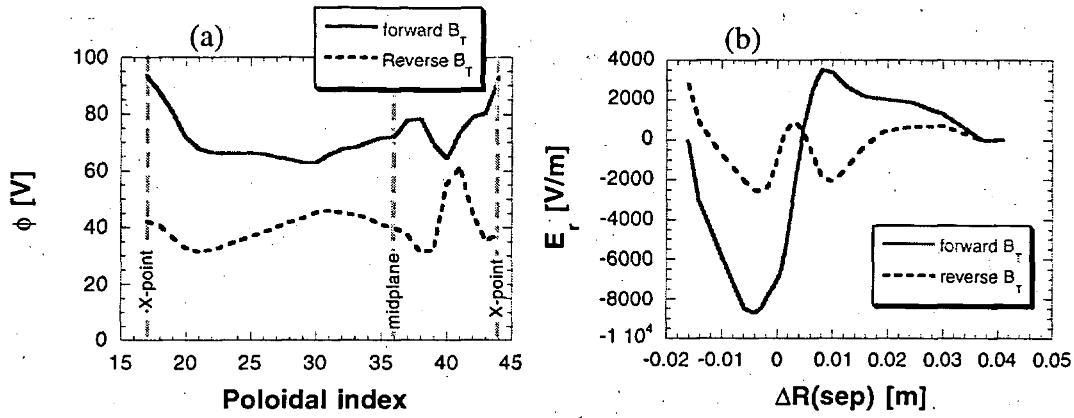


*Figure 2 The effect of reversing the toroidal magnetic field on the poloidal structure of the plasma potential (a), and the radial electric field at the outer midplane (b).*

when the electric field shear is sufficient to suppress turbulence created by the ITG instability. Smaller shear with reversed toroidal field, leads to more difficulty in achieving the H-mode, as seen experimentally. The change in the radial flow velocity obtained by reversing the toroidal field moves the maximum density gradient at the outer midplane outward by about 8 mm, but has little effect on the radial profile of the electron temperature profile. The shift of the density profile is about one-half of the density scale length, and should be observable experimentally.

## 2.2 Effect of varying the heating power

Higher electron temperature achieved with increased heating power increases the plasma potential in the SOL, but the poloidal structure is not significantly altered. The radial electric field seen on closed lines has higher shear at higher heating power. If the electric field shear is important for suppression of turbulence, and thus for H-mode confinement, one would expect higher powers to lead to H-mode confinement, as seen experimentally.

## 2.3 Effect of biasing

The potential of the SOL plasma can be increased by positively biasing the DIII-D bias ring which maps to the first two centimeters of the SOL at the outer midplane. Biasing the ring essentially raises the SOL potential everywhere, except near the inner divertor plate which is grounded. A 75 V bias raises the potential of the closed field lines about 50 V, producing a slightly deeper radial electric field well. The increased shear in the electric field suggests that H-mode confinement can be obtained more easily with a positive bias. The largest effect of adding bias to the outer ring is seen on the inner divertor leg. Since the inner divertor remains grounded, large poloidal and radial electric fields are created in this region. Drifts obtained from these fields move the density maximum on the inner leg from near the inner strike point radially to the edge of the biased flux surfaces, and upward toward the X-point. In addition, the bias creates larger radial electric fields near the separatrix in the private flux region, enhancing the flow of plasma from the outer strike point to the inner.

# 3 The effect of plasma shape

The effect of changing plasma shape has been examined by simulating a lower single null L-mode plasma with high triangularity ($\delta$=0.78). This plasma has a total heating power of 1.8 MW. The edge density is comparable to the Ohmic plasma described above, but the edge temperature is about a factor of 2 higher, with a temperature of 200 eV at the 96% flux surface. The plasma potential on the closed field lines is somewhat higher than that shown in Fig. 1, as expected for the higher temperature, but the poloidal structure is similar. There is a maximum potential above the X-point, and a minimum at the top of the plasma. These extrema are derived from the effect of the $\nabla$B drift which is toward the X-point. There is significantly less structure in the potential between the outer midplane and the X-point than shown in Fig. 1. This suggests that some of this structure is obtained from small variations in the magnetic field created by poloidal coils lying near the plasma on the low field side. The effect of this fine magnetic field structure is minimized by moving the plasma toward the inner post, as is done for high triangularity plasmas.

# 4 Summary and conclusions

The effect of plasma drifts on the edge plasma of a diverted tokamak has been examined by simulation with the UEDGE code. It is found that drifts create significant poloidal variation of the plasma pressure and potential, even on closed field lines. The parallel pressure gradients are supported by ion parallel viscosity. The potential structure depends on the direction of the ion $\nabla$B drift. Strongly sheared radial electric fields are created with the $\nabla$B drift toward the X-point, leading to expectations that the H-mode will be more easily achieved in that configuration. The radial electric field is also affected by variation in heating power, and biasing of the SOL. The potential structure remains qualitatively similar for high and low triangularity plasmas.